THE CONSTRUCTION PHASES OF THE NEW NAGA HAMMADI BARRAGE COFFERDAMS

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ABSTRACT

The main purpose of this paper is to assess the hydraulic conditions of the River Nile during and after the construction of the New Naga Hammadi Barrage Cofferdams. These two cofferdams will be constructed upstream and downstream the construction pit of the New Barrage. For this purpose, a physical model for the River Nile at the location of the New Barrage was constructed with scale 1:30. The model test program included all constructions phases of the two cofferdams. The tests were carried out for the conditions before the construction, four intermediate construction phases and after completion of works. Each phase was tested under steady conditions for not less two hours

The results proved that a respective design including stability calculations must be prepared to prove the stability of the material of the two cofferdams especially in the first and third phases of construction, which have high velocities. Also, the periods of executing these phases need to be limited, i.e. the diversion canal should be opened after a short period and the complete closure of the upstream cofferdam (the fourth phase) should be executed as soon as possible after the third phase.

INTRODUCTION

In the period 1997 to 1999 the Consultants of New Naga Hammadi Barrage Project carried out a feasibility study for a new Barrage at Naga Hammadi. Extensive hydraulic model tests were performed in the Hydraulics Research Institute (HRI) to enhance the hydraulic performance of the project concept and to optimize the design of its structures. The results were summarized in hydraulic model investigations final report (New Naga Hammadi Report [4], [5], and [6]).

The Naga Hammadi Barrage Joint Venture (JV) has entered into contract with the Ministry of Water Resources and Irrigation (MWRI) for the construction of the Civil Works of Naga Hammadi Hydropower Project. The scope of the contract includes some hydraulic model studies to test the method of construction and the construction materials to be used for cofferdam construction with special regard to river closure. Consequently, A technical services contract was signed between (JV) and (HRI) for the above mentioned hydraulic model studies.

PURPOSE OF STUDY

The main purpose of this paper is to assess the hydraulic conditions of the River Nile during and after the construction of the New Naga Hammadi Barrage Cofferdams. These two cofferdams well be constructed upstream and downstream the construction pit of the New Barrage

HYDRAULIC MODEL

For the Hydraulic Model Tests, the existing Naga Hammadi Barrage hydraulic model available at HRI was used. The model covers a reach of 800m upstream of the new barrage and 1,200 m downstream it. The model has fixed bed, which locally can be covered with riprap. The model is some 70 m long and 20 m wide. The model is a free surface flow where internal and gravitational forces determine the hydraulic phenomena to be investigated. Therefore, the model was based on Froude similarity with the prototype. For best possible simulation of hydraulic phenomena with smallest possible scale effects, the geometrical scale of the barrage model was selected as 1:30, which was determined by the available space in the HRI model hall.

Figure (1) shows the general layout of the model. The barrage model was erected in a basin type foundation in the southern hall of the HRI. The basin is 20 m wide and 80 m long and its outer walls are one meter above the floor level of the hall. For details of model similarity, instrumentation, discharges, water levels, etc., see New Naga Hammadi Report [4], [5], and [6].

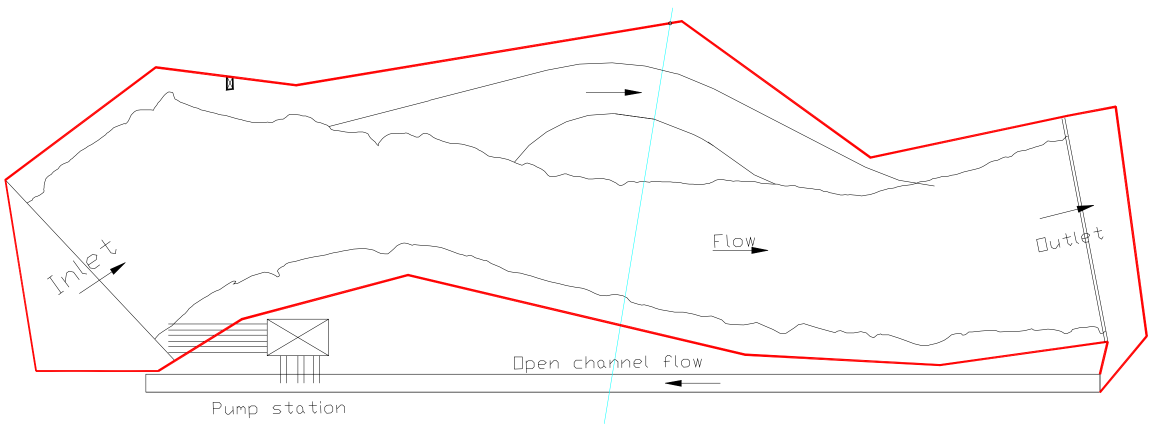

Figure (1) Barrage Model, General Layout

COFFERDAMS CONSTRUCTION

1 Concept of Cofferdam Construction

Before construction of the main structures (powerhouse, sluiceway, and navigation lock) the upstream and downstream cofferdams will be constructed. The diversion canal will be opened and the flow will be diverted into it. The construction of the two cofferdams will be through two embankments.

At the start of the upstream cofferdam construction, the river will flow through the diversion canal. With the progress of the construction, the upstream water level will increase and consequently more and more flow well be diverted to the diversion canal until no flow is discharged through the original riverbed at the end of the cofferdam construction.

2 Stages of Construction

For selected discharges, the stability of the construction material and riprap protection of the two cofferdams was assessed for different phases of dam construction. In the tests for cofferdams construction common construction methods were simulated

The following successive sequences were tested on the model:

- **Normal State:** The original condition of the River Nile. The Diversion Canal was not yet opened. The construction of the cofferdams was not started.
- **Phase 1:** First stage of construction of both cofferdams. Before the opening of the Diversion Canal some spurs were constructed on both banks of both cofferdams
- **Phase 2:** Opening of the Diversion Canal. The spurs erected in the previous phase were left unchanged
- **Phase 3:** Continuation of the construction of the right bank spur of the upstream cofferdam. The left bank spur was kept unchanged, the opening in the upstream cofferdam measured at river bed level between the toes of the two spurs was 20 m

  Phase 4: In this phase the residual gap between the two spurs from previous phase 3 was closed and the upstream cofferdam completed up to level 61m asl.

  Phase 5: Final state. Both cofferdams are completed and covered with riprap to provide protection against erosion by the water flow

3 Boundary Conditions

3.1 River discharge to be considered during model testing

The cofferdams are to be designed to withstand safely the diversion canal design flood, which is 2900 m^3/s. However the construction of the cofferdams was scheduled to take place from September 2003 to March 2004 when the river discharge is less than

1700 m^3/s. The very river closure was scheduled to take place in December 2003 when the river discharge is less than 1000 m^3/s.

The river discharges to be then considered during the successive testing sequences, which are thereafter detailed, were as follows:

- Testing of the normal state with the diversion canal not yet opened with river discharges of 1000, 1700 and 2900 m^3/s,
- Testing of the successive stages of construction of the cofferdams with river discharge 1000 and 1700 m^3/s
- Testing of the final state when both cofferdams are fully erected and protected with the Diversion Canal design flood i.e. 2900 m^3/s.

3.2 Water levels to be considered during model testing

The water levels were defined by rating curve applied to a location 200 m downstream of the sluiceway sill. The present rating curve (prototype conditions) is expressed by the following formula

$$\mathbf{WL = (0.1166 * Q^{0.5132}) + 55.5} \qquad \mathbf{(1)}$$

where

WL = water level downstream the weir of the existing Barrage, in m asl,
Q = river discharge, in m^3/s

4 Velocity Measurements Locations

Eight cross sections were chosen to measure the velocity profiles through them. In each profile the velocities were measured at three depths (0.2, 0.5, and 0.8 of the local water depth). The distance between two subsequent profiles was 15 m in prototype (50 cm in the model). The velocity was measured for each point in two directions V_{main} and $V_{transversey}$. V_{main} is the velocity measured in the direction perpendicular to the section line and $V_{transverse}$ is the velocity measured in the direction parallel to the section line. In the upstream side three sections were set (sec. 1, 2 and 3). Section 2 was set along the reference line of the upstream cofferdam, which is the alignment of the temporary sealing element in this cofferdam and section 1 and 3 were adjusted 50 m upstream and downstream of the reference line of the upstream cofferdam respectively. In the downstream side two sections were set (sec. 4 and 5). Section 4 was set along the reference line of the upstream cofferdam, which is the alignment of the temporary sealing element in this cofferdam and section 5 was adjusted 50 m downstream of it. In the diversion canal three sections were set. Sections 6 and 8 were set at the intake and outlet of the canal respectively and section 7 was set along the extension of the project axis. Figure (2) shows the locations of these sections.

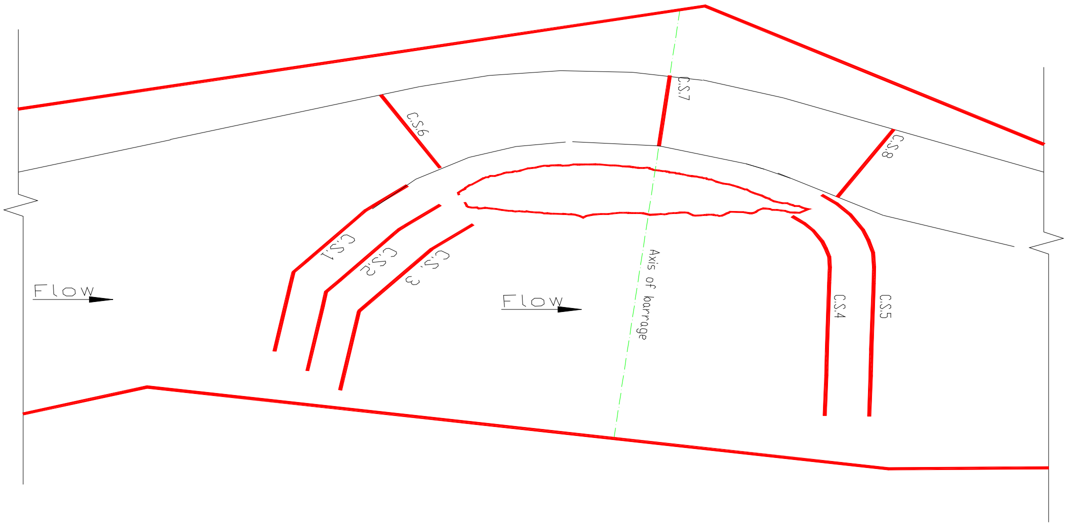

Figure (2) Measured Velocity Cross-Sections

For all phases the flow pattern (eddies, waves, backflow, etc…) was observed and recorded. The velocities were measured at three depths per profile (0.2, 0.5, and 0.8 of the local depth). The water levels upstream and downstream of the cofferdams were recorded. The passing discharges through the Diversion Canal and the main river bed was measured.

5 Construction Material of the Two Cofferdams

The main body of both cofferdams was formed with silty sand extracted from the site (simulated in the model by fine sand with D_{50} from 0.4 to 0.5 mm) and the use of rock fill was limited to the final closure (simulated in the model by riprap with D_{50} equal 6.26 and 4.62 mm. The riprap was putted on the outer sides of the two cofferdams with thickness equal to 50 cm in prototype.

TESTES SERIES

In order to test the cofferdam, the new Barrage was removed, the diversion channel was opened and the Riverbed was reformed according to the existing situation.

For construction of the cofferdams the test series as given in Table (1) were investigated in the Barrage Model.

Table (1) Summary of Test Runs

Phase Number	Test No.	Discharge (m^3/s)	W. L. 3 Km D.S. the Barrage (m)	Description
Zero	1 2 3	1000 1700 2900	59.54 60.80 62.48	River Nile in the original condition (the diversion canal is closed)
1	4 5	1000 1700	59.54 60.80	Spurs on both banks of both cofferdams (the diversion canal is closed)
2	6 7	1000 1700	59.54 60.80	Spurs on both banks of both cofferdams (the diversion canal is opened)
3	8 9	500 800 1000 1700	58.33 59.10 59.54 60.80	Continuation of the construction of the right bank spur of the upstream cofferdam
4	10 11	1000 1700	59.54 60.80	Completion of the upstream cofferdam up to 61 asl
5	12	2900	62.48	Completion of the two cofferdam up to 65 asl and covered with Riprap

The tests were carried out for the conditions before the cofferdams construction, four intermediate construction phases and after completion of works. Each phase was tested under steady conditions for not less two hours.

TEST RESULTS

1 Natural River Bed – Zero Stage

The normal state was used as a reference for the recorded water levels and flow velocities. In this phase the velocities were measured along the chosen eight sections.

The maximum velocities along the reference lines of the upstream and downstream cofferdams were respectively found at 60 to 140 m and 70 to 150 m from the left bank. Table (2) indicates the values of the maximum velocities for the three cases of discharges. The riverbed was found stable and remarkable flow phenomena were not observed.

Table (2) Maximum Velocities along the reference lines of the Upstream and Downstream Cofferdam (Zero Stage)

Discharge (m^3/s)	Water Level (m)	Velocity at the Reference line of the U.S cofferdam (Section 2) (m/s)	Velocity at the Reference line of the D.S cofferdam (Section 4) (m/s)
1000	59.54	0.78	0.64
1700	60.80	1.09	1.03
2900	62.48	1.51	1.35

2 First phase of Cofferdams Construction - Phase 1

Construction of the spurs on both banks of both cofferdams had a moderate effect on the flow conditions. A concentration of flow occurred close to the spurs of the upstream cofferdam due to the contraction of the river width by the two spurs, which increased the velocities values at that location. These velocities caused some erosion to the sides of the spurs parallel to the flow direction, which led to movement of the spurs materials from the top of the spurs sides slopes to its bottoms and hence the movement of these materials with the flow direction. Some vortices and separation zones were also observed upstream and downstream the spurs due to the contraction of river width as mentioned above which led to creation of contraction and expansion zones upstream and downstream the spurs.

The maximum velocities near the riverbed along the reference line of the upstream cofferdam were found equal 1.08 m/s at water level equal 59.54 m in case of discharge 1000 m^3/s and equal 1.68 m/s at water level equal 60.80 m in case of discharge 1700 m^3/s. Table (3) indicates the value of the maximum velocity along the reference line of each cofferdam for the two cases of discharges. These velocities indicate erosion and scouring between the spurs. Therefore the period of such high velocities needs to be limited, i.e. the diversion canal should be opened after a short period. These velocities also require an adequate riprap size to be stable and respective design including stability calculations must be prepared to prove this stability.

The contraction of the river width at the upstream spurs location led to raising the water level upstream the spurs about 9 and 16 cm in case of discharge 1000 and 1700 m3/s respectively.

Table (3) Maximum Velocities along the reference lines of the Upstream and Downstream Cofferdams (phase 1)

Discharge (m^3/s)	Water Level (m)	Velocity at the Reference line of the U.S cofferdam (Section 2) (m/s)	Velocity at the Reference line of the D.S cofferdam (Section 4) (m/s)
1000	59.54	1.17	1.26
1700	60.80	1.70	1.89

3 Second phase of Cofferdams Construction - Phase 2

After tests of phase 1 were concluded, the model was prepared to phase 2 tests. The diversion canal was opened and covered by the equivalent riprap. For more details of riprap properties it is referred to the Barrage Model Report on Hydraulic Model Investigations for the New Naga Hammadi Barrage, November 1999 [1]. The partly eroded shapes of the spurs, which happened in phase 1, were re-shaped to its original form.

After the opening of the diversion canal part of the flow tend to move in its direction. Therefore, The velocities in the main river became much lower and therefore became less critical than in the phase 1 tests.

The maximum velocities near the riverbed along the reference line of the upstream cofferdam were found equal 0.7 m/s at water level equal 59.54 m in case of discharge 1000 m^3/s and equal 0.89 m/s at water level equal 60.80 m in case of discharge 1700 m^3/s. Table (4) indicates the value of the maximum velocity along the two reference lines for both cofferdams for the two cases of discharges. The cofferdams material of all spurs and the riprap protection of bed and banks of the diversion canal remained stable at place. Negligible movement of the left upstream spur material in the flow direction was observed. Some small vortices and separation zones were also observed upstream and downstream the spurs.

The passing discharges through the main river and the diversion canal were calculated from the measured velocities and the water section area. It was found that the passing discharge in the diversion canal was nearly 50 % from the total discharge in both cases of discharges (1000 and 1700 m^3/s). The water level up stream the two spurs of the upstream cofferdam was nearly as its value in the zero stage for the case of discharge 1000 m^3/s and increased about 4 cm above its value in zero stage for the case of discharge1700 m^3/s.

Table (4) Maximum Velocities along the reference lines of the Upstream and Downstream Cofferdam (phase 2)

Discharge (m^3/s)	Water Level (m)	Velocity at the Reference line of the U.S. cofferdam (Section 2) (m/s)	Velocity at the Reference line of the D.S. cofferdam (Section 4) (m/s)
1000	59.54	0.74	0.61
1700	60.80	0.93	0.79

4 Third phase of Cofferdams Construction - Phase 3

Some pretests have been carried out before staring phase3 to evaluate whether, with the progressive narrowing of the residual gap between the two spurs of the upstream cofferdam, the velocities in this gap keep increasing or reach a peak much before the very river closure. Three successive situations have been modeled and tested with a constant discharge of 1700 m^3/s. These successive situations were executed by using vertical plate of wood has the same side slope of the upstream cofferdam. At each situation the closure was executed on successive steps as follows:

- The right bank spur was progressively extended in seven successive steps and the left bank spur from phase 2 was kept unchanged. By the end of the test the residual opening measured at the riverbed was 10 m between the toes of the two spurs.
- The left bank spur was progressively extended in eight successive steps and the right bank spur from phase 2 was kept unchanged. By the end of the test the residual opening measured at the riverbed was 22 m between the toes of the two spurs.
- Both spurs are progressively and simultaneously extended in six successive steps. By the end of the test the residual opening measured at the river bed was 4.5 m between the toes of the two spurs.

The results indicated that the velocities kept growing with the progressive reduction of the gap between the two spurs and apparently did not reach any intermediate peak. A strong flow concentration was observed immediately upstream of the residual gap. The velocities were reduced when the progressive narrowing was conducted from the right bank rather than from the left bank or from both banks. Upon these results, the contractor proposed phase 3 to be conducted as mentioned earlier in section 4.2.

The cofferdams material of all spurs and the riprap protection of bed and banks of the diversion canal remained stable at place except little movement of the slopes materials of the residual opening of the upstream cofferdam in the flow direction was observed. Also, some vortices were observed upstream and downstream the residual opening but remarkable high flow phenomena were not observed. The maximum velocities near the riverbed along the reference line of the upstream cofferdam were found equal 0.99

m/s at water level equal 59.54 m in case of discharge 1000 m^3/s and equal 1.3 m/s at water level equal 60.80 m in case of discharge 1700 m^3/s. Table (5) indicates the value of the maximum velocity along the two reference lines of both cofferdams for the two cases of discharges. The water level U.S the upstream cofferdam raised about 5 and 11 cm above its values in zero stage in case of discharge 1000 and 1700 m^3/s respectively.

The continuation of the construction of the spurs from the right bank of the upstream cofferdam caused a considerable diversion of the discharge through the diversion canal. The passing discharge through the diversion canal increased to nearly 70 % from the total discharge for both cases of discharge (1000 and 1700). A considerable distortion of the approach flow in the vicinity of the cofferdam sharply curved streamlines established.

The very river closure is scheduled to take place in December 2003 when the river discharge is less than 1000 m^3/s. So, the velocities were measured also for two cases of discharges (500 and 800 m^3/s) along the reference line of the upstream cofferdam and upstream and downstream it (sec.1, 2 and 3). The maximum velocities near the riverbed along the reference line of the upstream cofferdam were found equal 0.43 m/s at water level equal 58.33 m in case of discharge 500 m^3/s and equal 0.71 m/s at water level equal 59.10 m in case of discharge 800 m^3/s. The water level U.S the upstream cofferdam raised about 3 and 4 cm above its values in zero stage in case of discharge 500 and 800 m3/s respectively. A small distortion of the approach flow in the vicinity of the cofferdam sharply curved streamlines established.

Table (5) Maximum Velocities along the reference lines of the Upstream and Downstream Cofferdam (phase 3)

Discharge (m^3/s)	**Water Level (m)**	**Velocity at the Reference line of the U.S. cofferdam (Section 2) (m/s)**	**Velocity at the Reference line of the D.S. cofferdam (Section 4) (m/s)**
500	58.33	0.46	------
800	59.10	0.75	------
1000	59.54	0.99	0.50
1700	60.80	1.37	0.75

5 Fourth phase of Cofferdams Construction - Phase 4

In this phase the upstream cofferdam was fully closed and the flow passed through the diversion canal. The cofferdams material and the riprap protection of bed and banks of the diversion canal remained stable at place.

The maximum velocity in the diversion canal was found equal 1.13 m/s at water level equal 59.54 m respectively in case of discharge 1000 m^3/s and equal 1.51 m/s at water level equal 60.80 m in case of discharge 1700 m^3/s. Table (6) indicates the values of these velocities for the two cases of discharges. The water level U.S. the upstream cofferdam raised about 7 and 15 cm above its values in zero stage in case of discharge 1000 and 1700 m^3/s respectively.

Table (6) Max. Velocities Along Sec. No. 7 in the Diversion Canal (phase 4)

Discharge (m^3/s)	Water Level (m)	V at C.L of the project (Sec.7- Diversion Canal) (m/s)
1000	59.54	1.13
1700	60.80	1.51

6 Final Phase of Cofferdams Construction - Phase 5

In this phase the two cofferdams were completely constructed and the sides of the two cofferdams, which exposed to the water flow were covered by riprap with thickness 50 cm in prototype. For each side the two types of riprap R5 and R6 were used.

The riprap protection of the two cofferdams and the diversion canal remained stable at place. The maximum velocity in the diversion canal was found above 2.18 m/s. The riprap of the two cofferdams and the riprap protection of the bed and banks of the diversion canal remained stable at place. The water level upstream the upstream cofferdam was raised about 24 cm above its original value in zero stage.

Table (7) indicates the water levels U.S the upstream cofferdam and at the entrance of the diversion canal during all construction stages. Table (8) indicates the maximum velocities along the reference lines of the upstream and downstream cofferdam during all construction stages.

Table (7) Water Levels U.S. the Upstream Cofferdam During Construction Phases

Phase No.	River Discharge (m^3/s)	Downstream Water Level (m)	Recorded W. L. (m asl) U/S the upstream cofferdam
Zero	1000	59.54	59.54
	1700	60.80	60.80
	2900	62.48	62.48
1	1000	59.54	59.63
	1700	60.80	60.96
2	1000	59.54	59.54
	1700	60.80	60.84
3	1000	59.54	59.59
	1700	60.80	60.91
4	1000	59.54	59.70
	1700	60.80	60.95
5	2900	62.48	60.72

Table (8) Maximum Velocities Along the Reference Lines of the U.S. and D.S. Cofferdams During Construction

Phase No.	River Discharge (m^3/s)	D.S. Water Level (m)	Measured Velocity at Sec.2 (m/s)			Measured Velocity at Sec.4 (m/s)		
			80% of flow depth	50% of flow depth	20% of flow depth	80% of flow depth	50% of flow depth	20% of flow depth
Zero	1000	59.54	0.78	0.72	0.53	0.64	0.64	0.57
	1700	60.80	1.07	1.03	0.89	1.03	0.97	0.87
	2900	62.48	1.51	1.44	1.22	1.35	1.35	1.21
1	1000	59.54	1.17	1.13	1.08	1.26	1.17	1.12
	1700	60.80	1.66	1.70	1.61	1.89	1.81	1.56
2	1000	59.54	0.74	0.74	0.70	0.60	0.61	0.57
	1700	60.80	0.93	0.93	0.89	0.79	0.77	0.77
3	1000	59.54	0.90	0.93	0.99	0.50	0.45	0.34
	1700	60.80	1.37	1.30	1.30	0.75	0.68	0.64

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on the obtained results, it can be concluded that:

- In the zero stage (natural river) the maximum velocities along the reference lines of the upstream and downstream cofferdams were respectively found at 60 to 140 m and 70 to 150 m from the left bank. The riverbed was found stable and remarkable flow phenomena were not observed.

- In phase 1 the construction of the spurs on both banks of both cofferdams had a moderate effect on the flow conditions. A concentration of flow occurred close to the spurs of the upstream cofferdam due to the contraction of the river width by the two spurs, which increased the velocities values at that location. These velocities caused some erosion to the sides of the spurs parallel to the flow direction, which led to movement of the spurs materials from the top of the spurs sides slopes to its bottoms and hence the movement of these materials with the flow direction. Some vortices and separation zones were also observed upstream and downstream the spurs. The contraction of the river width at the upstream spurs location led to raising the water level upstream the spurs.

- In phase 2 the velocities in the main river became much lower due to the opening of the diversion canal and therefore became less critical than in the phase 1. The cofferdams material of all spurs and the riprap protection of bed and banks of the diversion canal remained stable at place. Negligible movement of the left upstream spur material in the flow direction was observed. Some small vortices and separation zones were also observed upstream and downstream the spurs.

- Upon the results of the pretests, phase 3 was executed from the right side of the upstream cofferdam. The cofferdams material of all spurs and the riprap protection of bed and banks of the diversion canal remained stable at place except little movement of the slopes materials of the residual opening of the upstream cofferdam in the flow direction was observed. Also, some vortices were observed upstream and downstream the residual opening but remarkable high flow phenomena were not observed. The continuation of the construction of the spurs from the right bank of the upstream cofferdam caused a considerable diversion of the discharge through the diversion canal.

- In phase 4 the upstream cofferdam was fully closed and the flow passed through the diversion canal. The cofferdams material and the riprap protection of bed and banks of the diversion canal remained stable at place.

- In phase 5 (final phase) the two cofferdams were completely constructed and the sides of the two cofferdams, which exposed to the water flow, were covered by riprap with thickness 50 cm in prototype. The riprap of the two cofferdams and the diversion canal remained stable at place.

RECOMMENDATIONS

From these results it is recommended that a respective design including stability calculations must be prepared to prove the stability of the material of the two cofferdams especially in phase 1 and phase 3, which has high velocities. Also, the periods of executing these phases need to be limited, i.e. the diversion canal should be opened after a short period and the complete closure of the upstream cofferdam (phase 4) should be executed as soon as possible after phase 3.

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